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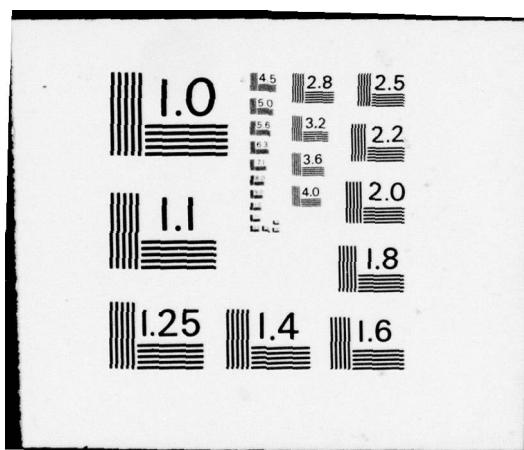
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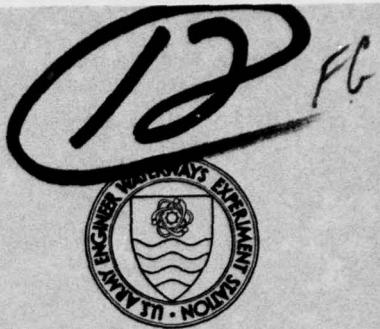
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TECHNICAL REPORT C-76-3

## EVALUATION OF ADMIXTURES FOR USE IN CONCRETE TO BE PLACED UNDERWATER

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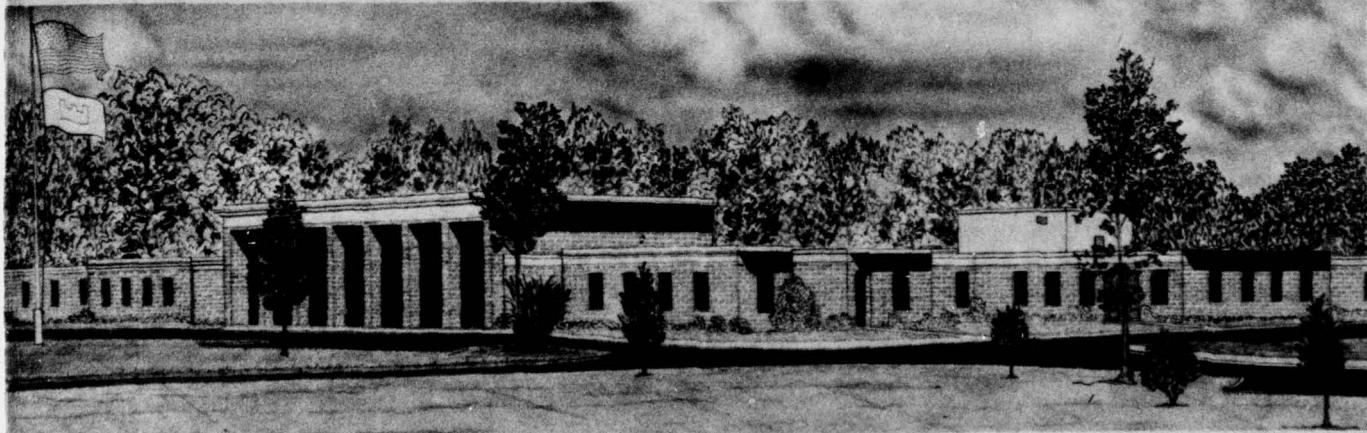
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U. S. Army Engineer Waterways Experiment Station  
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September 1976

Final Report

Approved For Public Release; Distribution Unlimited



Prepared for Office, Chief of Engineers, U. S. Army  
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Under Work Unit 31338

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number) Concrete without admixture and concrete containing either a plasticizer ("fluidifier") or a retarder were mixed and deposited underwater using the tremie method. The tremie used consisted of a pipe topped with a receiving funnel and plugged at the discharge end to keep the pipe sealed until filled with concrete. Tests were conducted with a number of batches of concrete to determine the slope and distance the concrete flowed. The tests were made to determine if these commercially available admixtures when used in concrete to be placed underwater increase the flowability of the concrete.		

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20. ABSTRACT (Continued):

Test results indicated that the use of either a retarding admixture or a plasticizer did not increase the flowability of equal-slump concrete, regardless of point of tremie discharge. The slope was not significantly affected by either a retarding admixture or a plasticizer. The concrete containing either a retarder or plasticizer appeared to be more cohesive and developed less laitance than equal-slump concrete without these admixtures.

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## **PREFACE**

The investigation reported herein was authorized as a part of Work Unit 31338 of the Civil Works R&D Program, "Improvements in Concrete Construction Practices," 19 June 1974.

The investigation was conducted at the Concrete Laboratory, U. S. Army Engineer Waterways Experiment Station (WES), in 1974-75 under the direction of Mr. Bryant Mather, Chief of the Concrete Laboratory. Members of the Concrete Laboratory staff actively concerned with the investigation included Messrs. John M. Scanlon, Jr., William O. Tynes, and Willard B. Lee. This report was prepared by Mr. Tynes.

Messrs. R. J. Schutz and J. Wayman Williams contributed to the discussions included in the appendixes to this report.

Director of WES during the conduct of the investigation and the preparation and publication of this report was COL G. H. Hilt, CE. Technical Director was Mr. F. R. Brown.

## **CONTENTS**

	<u>Page</u>
PREFACE .....	2
CONVERSION FACTORS, U. S. CUSTOMARY TO METRIC (SI) UNITS OF MEASUREMENT .....	4
PART I: INTRODUCTION .....	5
Background .....	5
Objective .....	5
Scope .....	5
PART II: MATERIALS, MIXTURES, EQUIPMENT, AND TESTING PROCEDURES .	7
Materials .....	7
Mixtures .....	7
Equipment .....	7
Test Procedures .....	9
PART III: RESULTS AND DISCUSSION .....	13
Slope of the Concrete .....	13
Flowability of Concrete .....	15
PART IV: CONCLUSIONS .....	17
REFERENCES .....	18
TABLES 1-4	
APPENDIX A: SUBSEQUENT DISCUSSION	
APPENDIX B: DISCUSSION WITH J. WAYMAN WILLIAMS	

## **CONVERSION FACTORS, U. S. CUSTOMARY TO METRIC (SI) UNITS OF MEASUREMENT**

U. S. customary units of measurement used in this report can be converted to metric (SI) units as follows:

Multiply	By	To Obtain
inches	25.4	millimetres
feet	0.3048	metres
yards	0.9144	metres
miles (U. S. statute)	1.609344	kilometres
square feet	0.09290304	square metres
square yards	0.8361274	square metres
cubic feet	0.02831685	cubic metres
cubic yards	0.7645549	cubic metres
ounces, fluid	29.57353	cubic centimetres
pounds per cubic yard	0.59327631	kilograms per cubic metre
pounds (force) per square inch	0.006894757	megapascals

# EVALUATION OF ADMIXTURES FOR USE IN CONCRETE TO BE PLACED UNDERWATER

## PART I: INTRODUCTION

### BACKGROUND

1. Three principal problems must be dealt with in placing concrete underwater by the use of a tremie:<sup>1</sup> (a) the necessity of thoroughly cleaning the area to be concreted; (b) the workability and uniformity of the concrete; and (c) the establishment and maintenance of the tremie seal. These and other problems of placing concrete underwater by the tremie method are discussed by Angas, Shanley, and Erickson.<sup>2</sup>

2. The CE Guide Specifications for Concrete for Civil Works (CE-1401.01)<sup>3</sup> permit concrete to be deposited in water through a tremie or pipe. Horizontal flow of up to 15 ft (5 m)\* for nonretarded concrete and 20 ft (6 m) for retarded concrete is allowed. Recent field experience at the Uniontown Dam in the U. S. Army Engineer Division, Ohio River, has indicated that a satisfactory job may be obtained even when retarded concrete is allowed to flow up to 30-35 ft (9-11 m) from point of deposit.

3. Concrete deposited underwater must not be agitated any more than is required to secure proper placement. Excess agitation causes loss of cement and weak concrete. Vibration is not permitted. Placement through tremies or pipes is essential, but expensive; therefore, it is economically desirable to use a minimum number of tremies. The problem is compounded by the difficulty of viewing and directing the placement operation from the surface. Various methods of improving the placement of concrete underwater have been attempted, but the problem of obtaining concrete of a satisfactory quality still exists. Questions have arisen as to how many tremies are necessary (i.e., how far apart they should be when using the tremie method). It has been reported<sup>4</sup> that: "Simultaneously placing through more than one tremie is recommended where all the concrete cannot be placed from one position. It is usual practice for a single tremie pipe to serve an area of about 30 m<sup>2</sup> (300 ft<sup>2</sup>) but this is an arbitrary limit which may be increased with experience." If research indicates that the use of a retarding or fluidifying admixture would allow concrete to be moved horizontally underwater up to 30-35 ft (9-11 m) without detrimentally affecting the final product, substantial savings could be achieved.

### OBJECTIVE

4. The objective of this study was to determine if commercially available admixtures, when used in concrete to be placed underwater, increase the flowability of the concrete without detrimentally affecting the final product.

### SCOPE

5. Concrete without admixture and concrete containing either a plasticizer ("fluidifier") or a

\* A table of factors for converting U. S. customary units of measurement to metric (SI) units is presented on page 4.

retarder were mixed and deposited underwater using the tremie method. The tremie used consisted of a pipe topped with a receiving funnel and plugged at the discharge end to keep the pipe sealed until filled with concrete. Tests were conducted with a number of batches of concrete to determine the slope and the distance the concrete flowed.

## **PART II: MATERIALS, MIXTURES, EQUIPMENT, AND TESTING PROCEDURES**

### **MATERIALS**

#### **Portland Cement**

6. Type II portland cement (RC-705) from Alabama was used for all concrete made during the investigation. The chemical and physical properties of the cement are presented in Table 1.

#### **Aggregates**

7. The fine (WES-1 S-4(51)) and coarse (CL-2 G-2) natural aggregates were obtained from Mississippi. The aggregates were graded to meet the requirements of CE-1401.01.<sup>3</sup> The gradings and physical properties of the aggregates are presented in Table 2.

#### **Air-Entraining Admixture**

8. The air-entraining admixture (AEA-918) used in the investigation was a solution of neutralized vinsol resin.

#### **Retarder**

9. The retarding admixture (AD-500) was a lignosulfonate in liquid form. The material was checked for compliance with CRD-C 87, Type B.<sup>5</sup> The results are shown in Table 3.

#### **Fluidifier (Plasticizer)**

10. The fluidifier (AD-420) was a proprietary product for which no data as to class or composition were given.

### **MIXTURES**

11. Four concrete mixtures were proportioned to meet the requirements for underwater placement (i.e., each mixture contained 3/4-in. (19.0-mm) maximum size natural aggregate, 600 lb/cu yd (356 kg/m<sup>3</sup>) of portland cement, and an air content of 4.5 + 0.5 percent). These mixtures were designated 1 through 4. Mixture No. 1 was proportioned as the basic mixture with a slump of 6-1/2 + 1/2 in. (165 + 13 mm). Mixture No. 2 contained a retarder and Mixture No. 3 contained a fluidifier. Mixtures No. 2 and 3 were adjusted to have approximately the same slump as Mixture No. 1. Mixture No. 4 was the same as Mixture No. 1 except it contained a retarder. The slump for Mixture No. 4 was not controlled and the slump was approximately 8-1/4 in. (209.55 mm). Four batches of concrete were made from Mixtures No. 1 and 2. Two batches were made from Mixture No. 3 and three batches from Mixture No. 4. The sand:aggregate ratio (S/A) was 43 percent for all mixtures.

### **EQUIPMENT**

12. A form approximately 16 ft (5 m) long, 4 ft (1.2 m) high, and 1.5 ft (0.5 m) wide with Plexiglas on one of the 4- by 16-ft (1.2- by 5-m) sides (Figure 1) was used in this investigation. The Plexiglas supported side made it possible to observe the concrete as it was placed underwater.

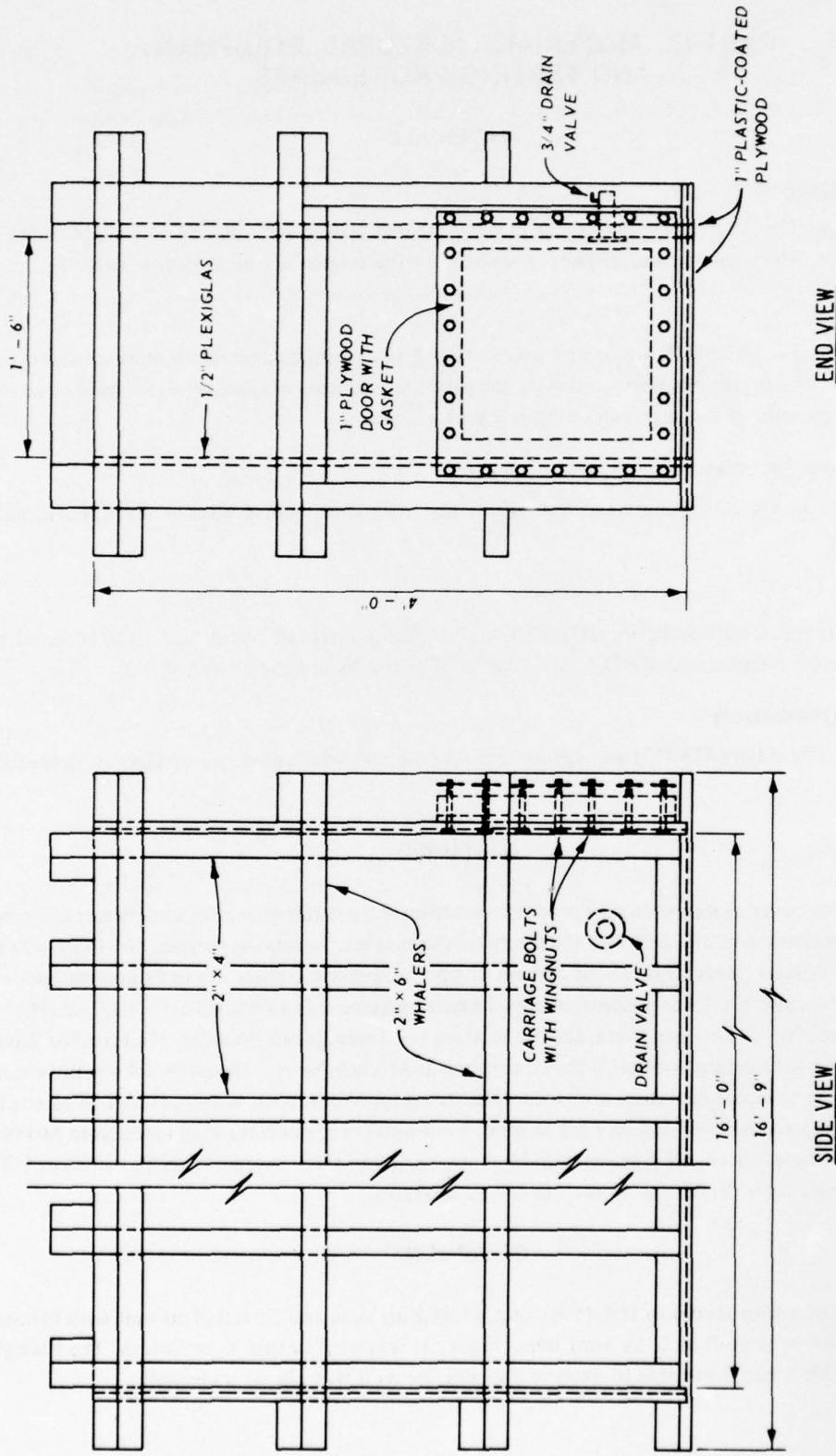


Figure 1. Sketch of Plexiglas form used to observe tremie concrete

13. A conical hopper, with a capacity of approximately  $16 \text{ ft}^3$  ( $0.45 \text{ m}^3$ ), from which a pipe extended (Figure 2) was used to place concrete into the form described in paragraph 12. A forklift was used to place and remove the hopper and pipe and hold the form in place while the fresh concrete was being discharged into the form.

#### TEST PROCEDURES

14. The test procedure began with filling the form with water. A forklift was then used to maneuver the hopper and tremie pipe so that the pipe could be placed into the form about 6 in. (152 mm) from one end and lowered to about 10 in. (254 mm) from the bottom (see Figure 3). The lower end of the pipe was sealed with a rolled bundle of burlap prior to lowering the pipe into the water. The concrete was mixed in  $15\text{-ft}^3$  ( $0.42\text{-m}^3$ ) size batches. A representative sample of concrete from each batch was tested for air content and slump. After these tests were made the sample batch of concrete was discharged from the mixer into a self-dumping mine bucket. Another forklift was used to transport the bucket of concrete to the form where it was discharged into the tremie hopper. Each test consisted of one batch of concrete. Figure 4 shows the form, forklift with hopper, and forklift with concrete being discharged from the bucket. Figure 5 shows water overflowing from the form after the concrete had been discharged into the form. After the concrete had passed through the tremie pipe, the slope was determined by measuring the height of the concrete in the form at 12-in. (305-mm) intervals along the horizontal length of the form. The flowability (distance the concrete flowed) was also measured. Two batches of concrete (two tests) were made on all four mixtures, with the tremie pipe located at one end.

15. After these tests were completed, three additional tests were made (one each for Mixtures No. 1, 2, and 4). The only difference in the testing procedure was the location of the tremie pipe. The pipe was moved from the end to the middle (center) of the form. The slope of concrete and distance flowed were determined as described in paragraph 14.

16. The tests described in paragraph 15 were repeated for Mixtures No. 1 and 2 with the tremie pipe placed flat on the bottom of the form; the concrete was discharged into the hopper with the pipe raised about 8 in. (203 mm) to allow removal of the packer. The slope of concrete and the distance the concrete flowed were determined as described in paragraph 14.

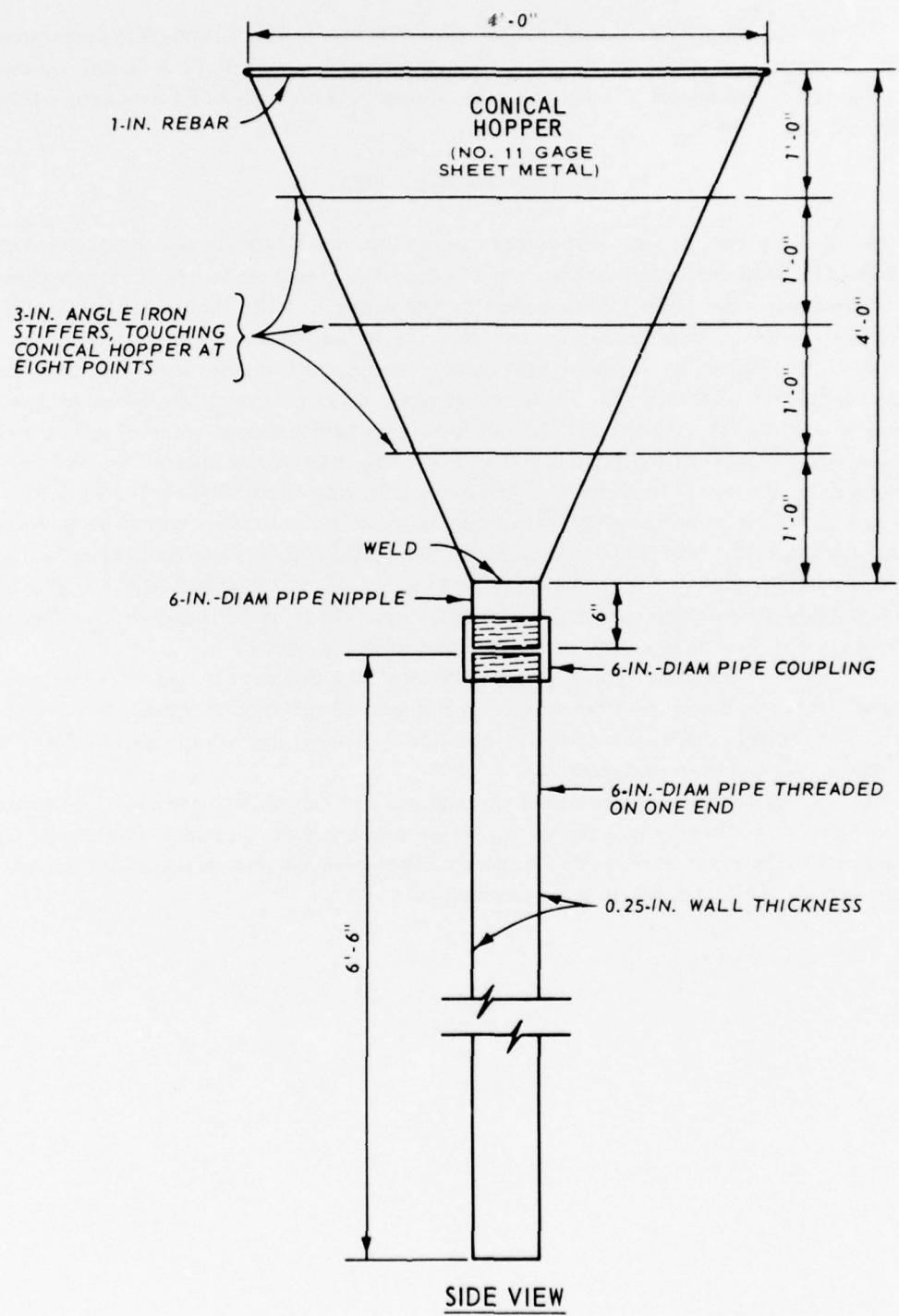


Figure 2. Sketch of conical hopper and pipe for placing concrete underwater



Figure 3. Form with the tremie pipe positioned at one end

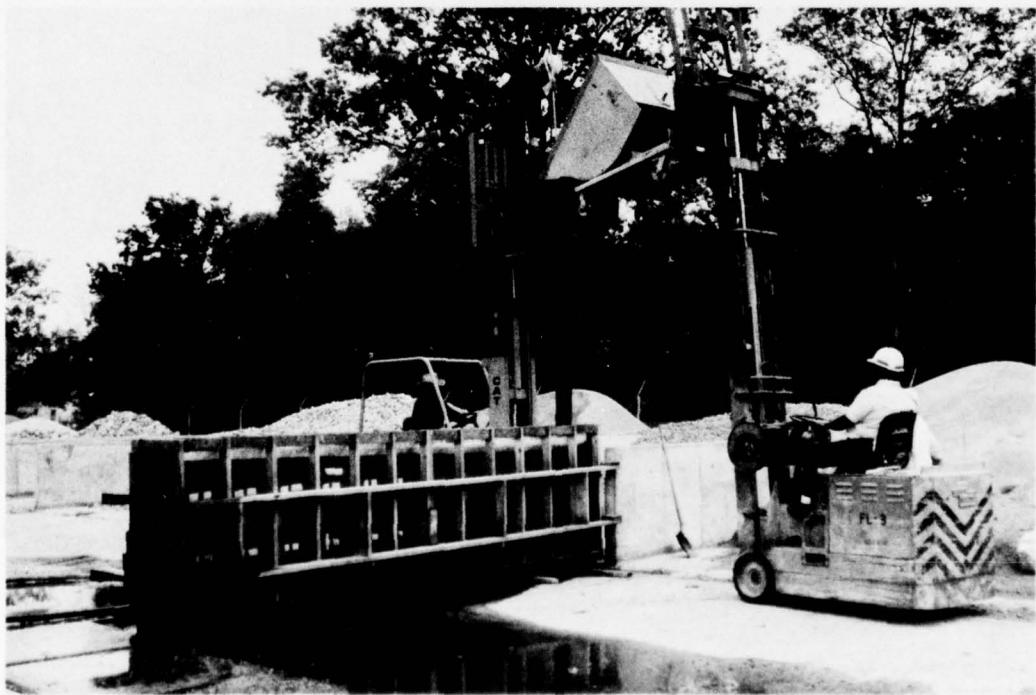


Figure 4. Concrete being discharged from bucket into the water-filled form

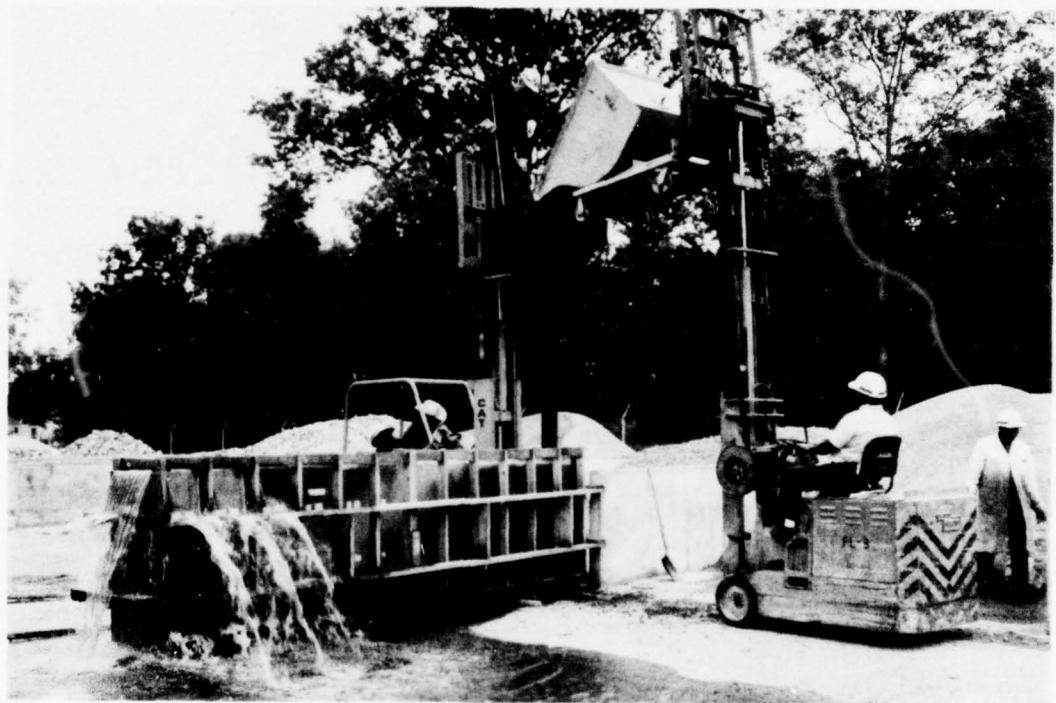


Figure 5. Water overflow after concrete discharge through tremie pipe

## PART III: RESULTS AND DISCUSSION

### SLOPE OF THE CONCRETE

17. For the first series of tests, in which the tremie pipe was located near one end of the form, the values for average height of two tests for each mixture (Nos. 1, 2, 3, and 4) are plotted in Figures 6, 7, 8, and 9, respectively, indicating the slope of the concrete. A comparison of the slopes of these four mixtures is shown in Figure 10. The individual height measurements of the different mixtures and different locations of the tremie pipe are shown in Table 4. It has been reported<sup>6</sup> that slopes of the surface of tremie concrete vary from 1:3 to 1:12. The results of these tests appear to fall within this range. The angle of repose can be calculated from the slopes of the curves for each mixture. The slopes of the curves were similar to some reported by Gjorv.<sup>7</sup>

18. The test results of the concrete placed through the tremie pipe in the middle and center of the form instead of at one end for Mixtures No. 1, 2, and 4 are plotted in Figure 11. The slopes are similar to those discussed in paragraph 17.

19. The test results of the concrete placed through the tremie pipe in the middle and center of the form and flat on bottom of the form for Mixtures No. 1 and 2 are plotted in Figure 12. The slopes are very similar to those described in paragraph 17.

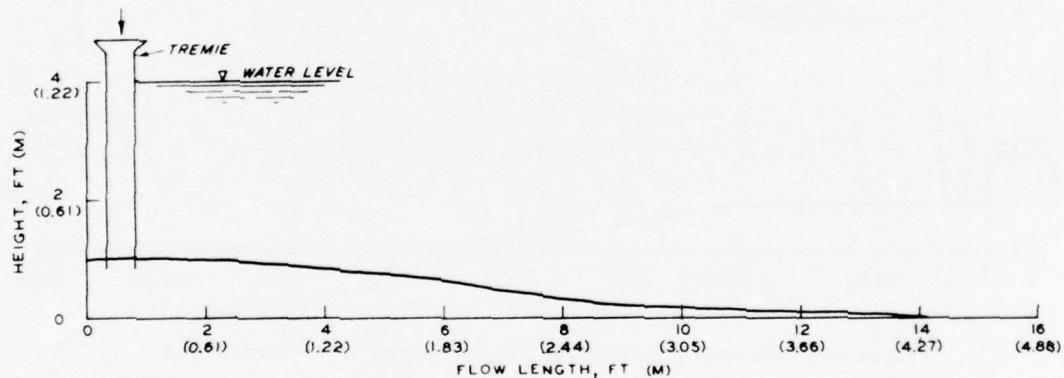


Figure 6. Average slope of concrete and distance concrete flowed (Mixture No. 1)

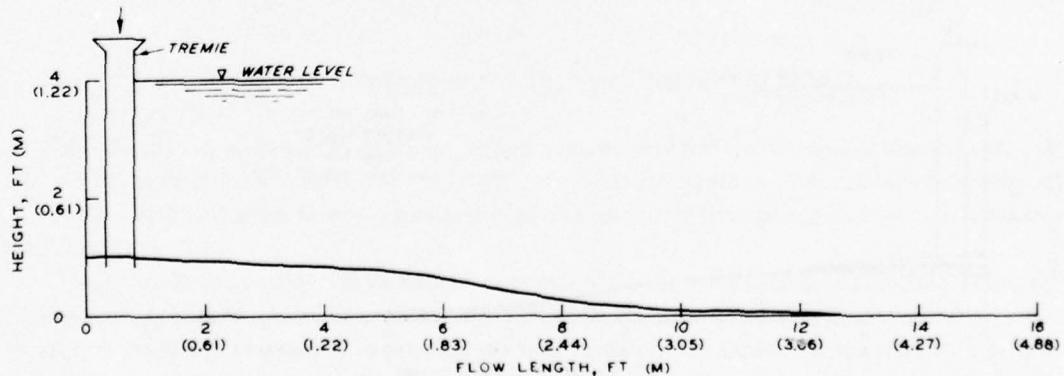


Figure 7. Average slope of concrete and distance concrete flowed (Mixture No. 2)

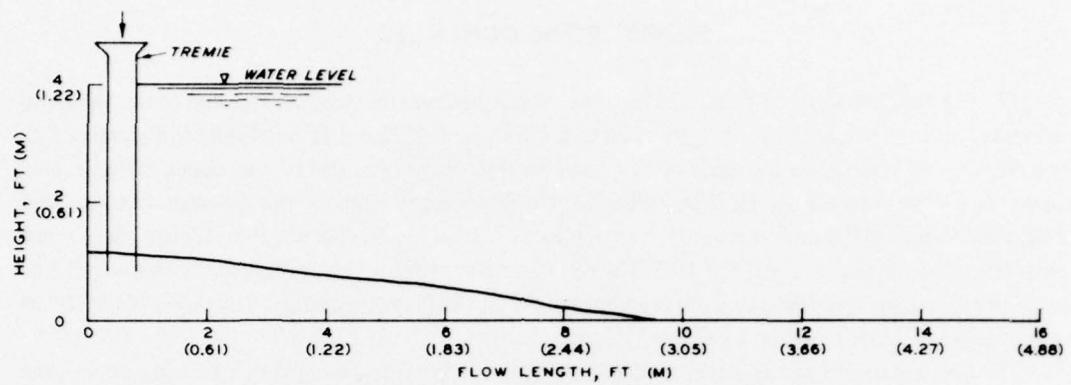


Figure 8. Average slope of concrete and distance concrete flowed (Mixture No. 3)

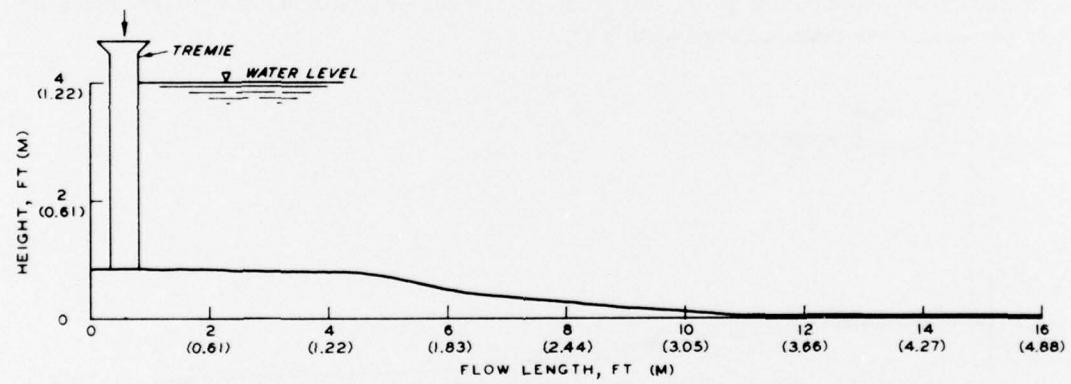


Figure 9. Average slope of concrete and distance concrete flowed (Mixture No. 4)

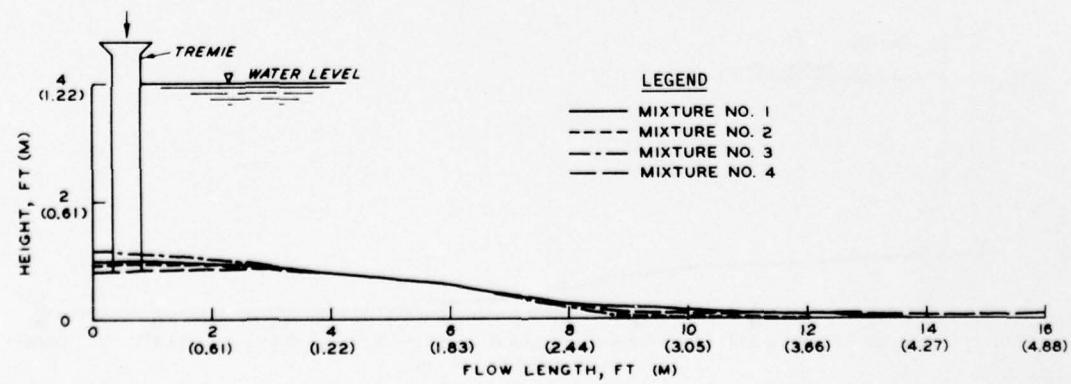


Figure 10. Comparison of the slopes of the four concrete mixtures

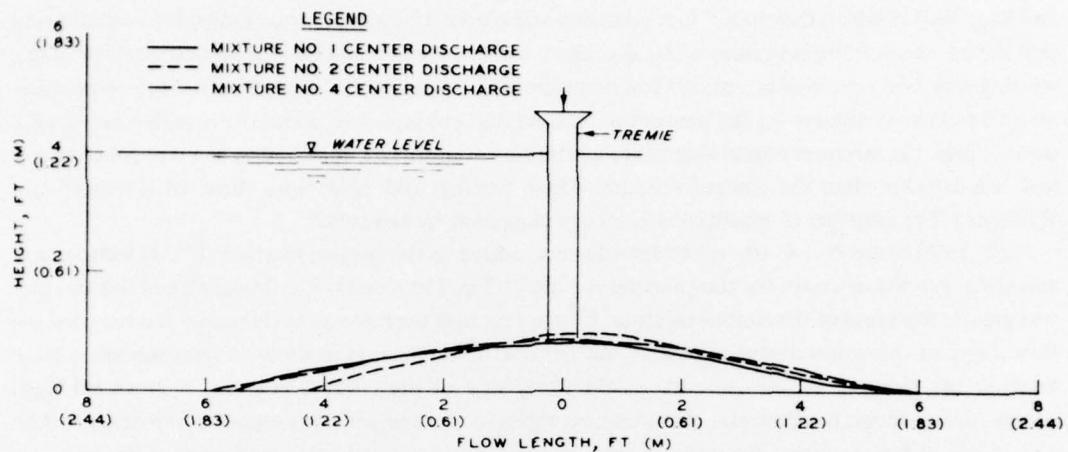


Figure 11. A comparison of the slopes of the concrete of Mixtures No. 1, 2, and 4; tremie at center of form instead of at one end

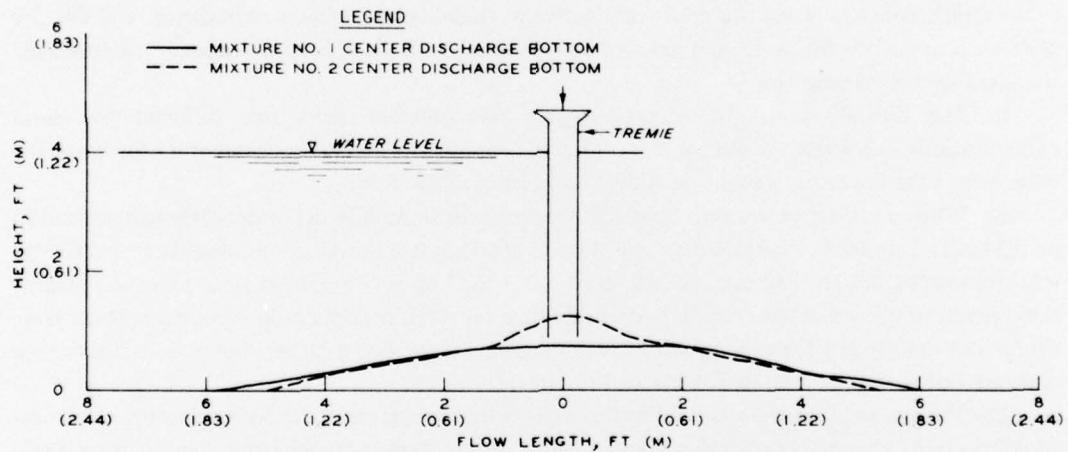


Figure 12. A comparison of the slopes of the concrete of Mixtures No. 1 and 2; tremie at center and flat on bottom of form

## FLOWABILITY OF CONCRETE

20. The average distances the concrete flowed underwater when the tremie pipe was located near one end of the form for Mixtures No. 1 through 4 are shown in Figures 6, 7, 8, and 9, respectively. A comparison of the distances flowed is shown in Figure 10 and the individual distances of each batch are shown in Table 4.

21. When the tremie pipe was located near one end of the form, the control mixture (No. 1) flowed approximately 14 ft (4.27 m); Mixture No. 2, 13 ft (3.96 m); Mixture No. 3, 9-1/2 ft (2.90 m), and Mixture No. 4, 16 ft (4.88 m). The concrete of the control mixture flowed farther than the mixture containing a retarding admixture (No. 2) and the one containing a plasticizing admixture (No. 3). These three mixtures had relatively the same slump. This does not agree with some of the findings of Gerwick<sup>6</sup>

and Williams<sup>8</sup> in which they found that retarding and plasticizing admixtures improved flowability and that the use of admixtures permits wider spacing of tremie pipes. It can be noted that the concrete in this investigation was restricted at one end and it could only flow in one direction. Observations were made on all batches of concrete for the amount of laitance and cohesiveness. In mixtures with relatively the same slump, the mixtures containing either a retarder or plasticizer appeared to be more cohesive and had less laitance than the control mixture. These findings did agree with those of Gerwick<sup>6</sup> and Williams.<sup>8</sup> The addition of plasticizers has been suggested by Greeves.<sup>9</sup>

22. In Mixture No. 4, where the retarder was added to the control mixture (No. 1) without any adjustment to the mixture, the slump increased about 2 in. (50.8 mm). The flowability of this mixture was greater than that of the control mixture. This agrees with the findings of Gerwick.<sup>6</sup> It is true that the flowability of this mixture was increased, but because of an increase in slump, a question arises as to whether the strength of this mixture would equal that of the control mixture. It appeared from observation through the Plexiglas that more segregation resulted with this higher slump mixture than with those of lower slump. No strength tests were made to validate this observation. Gerwick<sup>10</sup> has reported that: "Recently Dutch engineers have made extensive investigations into tremie concrete mixes. Reportedly, they favor the inclusion of 2 to 3 percent (by weight, related to total mix) of bentonite in the tremie concrete. They find that it promotes workability and reduces segregation, and that the concrete is not very sensitive to inadvertent variation in proportions of bentonite added." No bentonite was used in this investigation.

23. The flowability of the three mixtures was checked using two different placement configurations: one where the discharge was located near one end and in the center of the form; and the other where the discharge was in the middle and center of the form.

24. When the concrete was placed through the tremie in the middle and center of the form (about 10 in. (254 mm) from the bottom) the concrete of the control mixture flowed approximately 11-1/2 ft (3.50 m); Mixture No. 2, 10 ft (3.05 m); and Mixture No. 4, 12 ft (3.66 m). Regardless of the point of discharge the concrete of the control mixture flowed farther than the mixture containing a retarder with the same slump and slightly less than the mixture containing a retarder with a higher slump. The distance the concrete flowed can be seen in Table 4 and Figure 11.

25. The results of concrete flowability through the tremie pipe located at center-bottom of the form for Mixtures No. 1 and 2 are plotted in Figure 12. The distance flowed of each batch is also given in Table 4. Mixture No. 1 flowed approximately a distance of 12 ft (3.66 m) while Mixture No. 2 flowed approximately 10-1/2 ft (3.20 m). These distances approximate those when the tremie pipe was placed in the center but not placed on the bottom of the form.

26. The results obtained using the retarder and fluidifier in concrete placed underwater should be used with caution due to the limited laboratory investigations. However, comparisons of the different concrete mixtures with regard to flowability and slope should indicate overall typical differences or effects between mixtures.

## PART IV: CONCLUSIONS

27. Based on the results of this investigation the following statements appear justified:

- a. The use of either a retarding admixture or a plasticizer did not increase the flowability of equal-slump concrete, regardless of point of tremie discharge.
- b. When a retarder was added to a concrete mixture without any adjustment of the components of the mixture the flowability of the concrete was increased.
- c. The use of either a retarding admixture or a plasticizer did not affect the slope significantly, regardless of point of tremie discharge.
- d. The concrete containing either a retarder or plasticizer appeared to be more cohesive and developed less laitance than equal-slump concrete without these admixtures.
- e. The higher slump concrete mixture containing a retarder appeared to be less cohesive than all mixtures with a lower slump.

28. Confirmation of these results and evaluation of related opinions and recommendations can be accomplished most efficiently by observing tremie performance under actual field conditions. Field offices having projects where tremie construction will be used are urged to offer the Waterways Experiment Station Concrete Laboratory the opportunity to conduct observations of tremie performance and results.

29. The paragraph -12.10 requirement contained in Guide Specification CE-1401.01 allowing a greater tremie spacing interval (20 ft (6 m)) when a retarding admixture is used does not appear justified. A single maximum horizontal flow of 15 ft (5 m) should be specified. This distance limit may be conservative for open and extensive placement areas or when improvement in mixture characteristics through use of admixtures can be demonstrated. Design of a tremie concrete mixture should consider possible benefits from use of admixtures and pozzolans.

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**Table 1**  
**Chemical and Physical Properties of**  
**Type II Portland Cement**

Tests for	Type II, RC-705
<u>Chemical Properties</u>	
SiO <sub>2</sub> , %	22.8
Al <sub>2</sub> O <sub>3</sub> , %	4.0
Fe <sub>2</sub> O <sub>3</sub> , %	4.2
CaO, %	62.8
MgO, %	3.5
SO <sub>3</sub> , %	1.7
Loss on ignition, %	0.6
Insoluble residue, %	0.26
Na <sub>2</sub> O, %	0.12
K <sub>2</sub> O, %	0.49
Total alkalies, Na <sub>2</sub> O, %	0.44
C <sub>3</sub> S, %	45.6
C <sub>2</sub> S, %	30.9
C <sub>3</sub> A, %	3.5
C <sub>4</sub> AF, %	12.7
<u>Physical Properties</u>	
Specific gravity	3.15
Fineness, air permeability, cm <sup>2</sup> /g	3150
Setting time, Gillmore, Hours:Minutes	
Initial	3:15
Final	5:45
Autoclave expansion, %	0.10
Air content, %	8.4
Compressive strength, psi 3 days age	1630
7 days age	2280

**Table 2**  
**Gradings and Physical Properties of Fine and Coarse Aggregates**

	<b>Coarse Aggregate CL-2 G-2</b>	<b>Fine Aggregate (Sand) WES-1 S-4(51)</b>
Specific gravity	2.56	2.64
Absorption, %	1.9	0.2
Fineness modulus	6.61	2.79
Gradation, cumulative percent passing sieve size:		
3/4 in.	100.0	
1/2 in.	63.0	
3/8 in.	35.0	100.0
No. 4	3.0	98.0
No. 8		87.0
No. 16		72.0
No. 30		46.0
No. 50		15.0
No. 100		3.0

**Table 3**  
**Results of Tests of Retarding Admixture (AD-500)\***  
**(Testing According to CRD-C 87<sup>5</sup>)**

<b>Tests</b>	<b>Results</b>	<b>Specified Requirements</b>
Water content, percent of control	94	
Initial setting time control	5 hr 35 min	
With admixture	7 hr 0 min	
Deviation from control	1 hr 25 min	At least 1 hr later, not more than 3-1/2 hr later
Final setting time control	8 hr 30 min	
With admixture	10 hr 0 min	
Deviation from control	1 hr 30 min	Not more than 3-1/2 hr later
3-day compressive strength control, psi (MPa)	1630 (11.2)	
With admixture	2300 (15.9)	
Percent of control	141	90 min
7-day compressive strength control, psi (MPa)	2050 (14.1)	
With admixture	2890 (19.9)	
Percent of control	141	90 min
28-day compressive strength control, psi (MPa)	3840 (26.5)	
With admixture	4410 (30.4)	
Percent of control	114	90 min

\* 7.4 oz (218.8 cc) of retarding admixture per cwt of cement was used.

**Table 4**  
**Test Results of Height of Concrete and Distance Flowed Underwater**

Mix-ture No.	Batch No.	Height of Concrete at 1-ft Intervals Horizontally; End Discharge 10 in. from Bottom										Distance Concrete Flowed						
		0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
1	1	1.0	1.0	0.96	0.93	0.80	0.65	0.65	0.40	0.30	0.20	0.15	0.11	0.10	0.04	0.01	14 (4.27)	
	2	1.0	1.0	0.96	0.93	0.80	0.75	0.60	0.40	0.30	0.20	0.15	0.09	0.05	0.04	0.01	14 (4.27)	
2	Avg	1.0	1.0	0.96	0.93	0.80	0.70	0.62	0.40	0.30	0.20	0.15	0.10	0.08	0.04	0.01	13 (3.96)	
	1	1.0	1.0	0.92	0.86	0.80	0.73	0.60	0.40	0.30	0.15	0.082	0.060	0.050	0.01	13 (3.96)		
2	Avg	1.0	1.0	0.92	0.86	0.80	0.73	0.60	0.38	0.20	0.13	0.081	0.040	0.030	0.01	13 (3.96)		
	2	1.0	1.0	0.92	0.86	0.80	0.73	0.60	0.39	0.25	0.14	0.081	0.050	0.040	0.01	9-1/2 (2.90)		
3	1	1.3	1.25	1.05	0.88	0.80	0.75	0.56	0.40	0.20	0.08					9-1/2 (2.90)		
	2	1.0	1.00	0.97	0.86	0.70	0.65	0.52	0.36	0.20	0.12					9-1/2 (2.90)		
4	Avg	1.15	1.12	1.01	0.87	0.75	0.70	0.54	0.38	0.20	0.10					9-1/2 (2.90)		
	1	0.80	0.80	0.80	0.80	0.75	0.55	0.40	0.30	0.15	0.15	0.10	0.08	0.08	0.08	16 (4.88)		
4	2	0.90	0.90	0.80	0.80	0.65	0.45	0.40	0.30	0.25	0.15	0.10	0.10	0.10	0.10	16 (4.88)		
	Avg	0.85	0.85	0.80	0.80	0.70	0.50	0.40	0.30	0.20	0.15	0.10	0.09	0.09	0.09	0.09 (3.66)		
<b>Height of Concrete at 1-ft Intervals Horizontally; Center Discharge 10 in. from Bottom</b>																		
1	1	6	5	4	3	2	1	0	1	2	3	4	5	6				
		0.19	0.39	0.58	0.71	0.75	0.80	0.79	0.64	0.39	0.21	0.08	0.01	11-1/2 (3.50)				
2	1	0.17	0.38	0.58	0.83	1.00	0.92	0.71	0.50	0.33	0.13				10 (3.05)			
		0.13	0.29	0.57	0.75	0.80	0.80	0.80	0.79	0.62	0.33	0.17			12 (3.66)			
<b>Height of Concrete at 1-ft Intervals Horizontally; Center Discharge Flat on Bottom</b>																		
1	1	6	5	4	3	2	1	0	1	2	3	4	5	6				
		0.04	0.17	0.33	0.50	0.70	0.75	0.79	0.79	0.77	0.62	0.38	0.21	0.04	12 (3.66)			
2	1	0.29	0.46	0.65	0.88	1.25	0.96	0.71	0.50	0.33	0.17				10-1/2 (3.20)			

## **APPENDIX A: SUBSEQUENT DISCUSSION**

1. Subsequent to the completion of the underwater concrete placement work questions arose as to how a chemical admixture might be beneficially employed in concrete placed underwater by the tremie method.
2. One working hypothesis was developed from the following concept: If it takes x cu yd of concrete to fill up a caisson, bridge pier, etc., and y cu yd/hr of concrete can be forced down one tremie pipe, and if the time of initial set of the concrete is a hr, and y · a is less than x, then a retarder or more than one tremie is needed.
3. The underwater distance a mixture flowed from the end of the pipe was measured in this program. It was found that:
  - a. At equal slump (before setting) the absence or presence of a retarder has little effect.
  - b. Mixtures with higher slumps flow farther than those with lower slumps.
  - c. A form with a 1/2-mile radius could probably be filled using one center-placed tremie pipe, provided the concrete did not stiffen until completion.
  - d. A need existed to evaluate retarders effects on delaying stiffness and subsequently allowing a longer time period for continuous placement. This delay and longer placement time allow a greater lateral distance to be filled from one pipe.
4. The findings in this report seem to warrant a change to existing paragraph 12.10, pages 58-59, of CE-1401.01.\* These data also seem to indicate that high-slump mixtures should not be used due to their greater tendency to suffer a separation of mortar from the mass.
5. Investigations warranted include studies on:
  - a. Mixtures having lower slumps (3 to 4 in.).
  - b. Properties of horizontal joints when new concrete is placed on top of hardened laitance.
  - c. Acceptable distance between tremies.
  - d. Quality of the vertical joint formed by two separate tremie operations.

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\* Raised numbers refer to similarly numbered items in the References at the end of the main text.



## APPENDIX B: DISCUSSION WITH J. WAYMAN WILLIAMS

1. Following the discussions summarized in Appendix A, information was solicited from J. Wayman Williams, the author of the only important previous work on the subject of underwater concrete placement. J. Wayman Williams wrote "Tremie Concrete Controlled with Admixtures," Jour. Amer. Conc. Inst. Proc. Vol 55, Feb 1959, pp 839-850. The questions and answers follow:

Q1. Figure 2 of your report says "numbers indicate sequence of batches." The figure suggests that batch one was placed first, batch two placed on top of batch one, batch three placed on top of batch two, etc. This is not the way I understood it was done. Our CE book, EM 1110-2-2000, "Standard Practice for Concrete," says the pipe will be kept buried about 5 ft in the concrete. On this basis, it should be batch No. 1 that rides on top and finally is at the top (see Figure B1). Is Figure 2 of the paper labeled wrong, i.e., is batch "7" the first batch placed and batch "1" the seventh?

A1. You are correct that tremie concrete is not supposed to be placed one batch on top of another as the small samples show. However, the formwork for these samples was only 12 in. wide, and there was considerable resistance to flow. Consequently, it was necessary to raise the 4-in. tremie pipe to get any flow at all. The pipe itself, to my best recollection, was always about 6 in. into the concrete. Batches were placed in sequence 1 through 7. You can see batch 7 hardly showed at all on the sides of the form as it mostly displaced other batches.

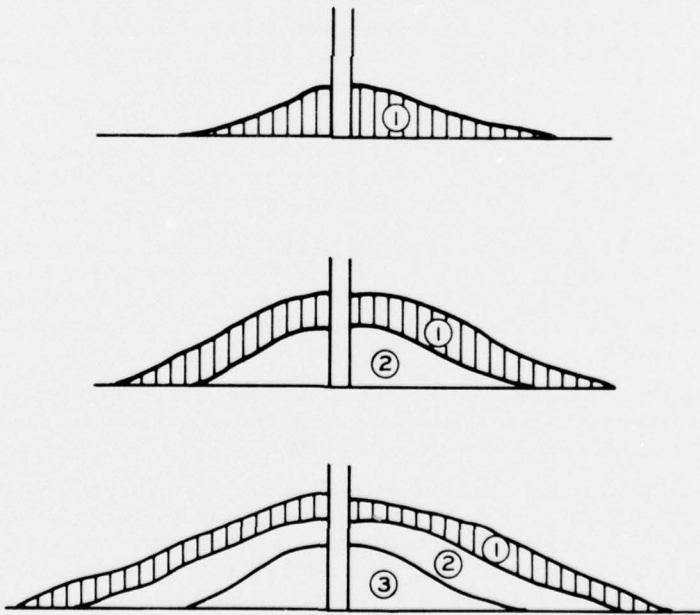


Figure B1. Layers of different batches of concrete

Q2. Figures 2 and 3 of your report show piles with fairly steep slopes. Figure 5 shows much gentler slopes and says the steeper part is due to interference by the piles. It also shows two pipes for about 80 ft of distance.

A2. Steep slopes are a direct result of the 12-in.-wide form. Gentle slopes in Figure 5 are typical of retarded concrete placed at a moderately rapid rate. Yes, two pipes were used in a single position for the first 9 hr, as indicated in Figure 6. Fewer pipes and less movement of pipes minimize laitance.

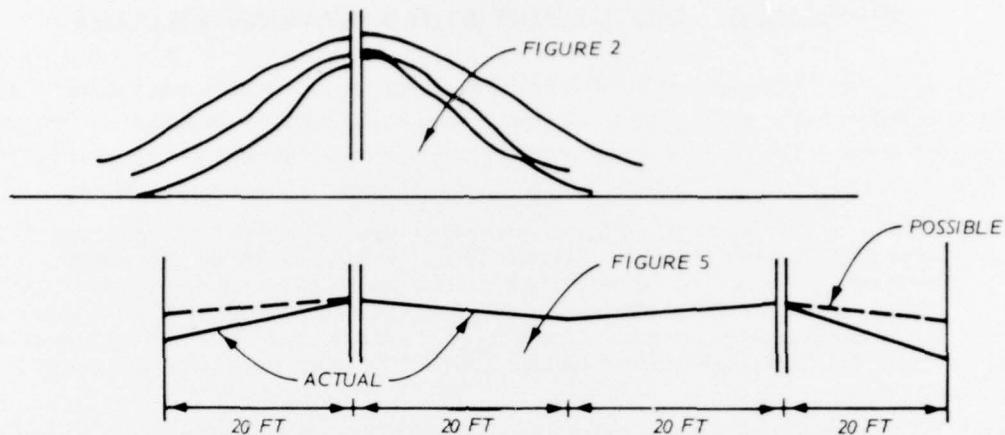


Figure B2. Comparison of slopes of rapidly placed (9 hr at 112 yd<sup>3</sup>/hr) concrete (Figure 5 of Williams' report) and slowly placed (2 hr and 20 min at 0.1 yd<sup>3</sup>/hr) concrete (Figure 2 of Williams' report)

- Q3. The lab work Williams reported was done with 8-in.-slump concrete. The Cofferdam (Figure 5) also used a slump of 8 to 9 in. Figure 5 shows slopes at the 9-hr age. Figure 2 shows slopes at 7 × 20 min = 140 min = 2 hr and 20 min. Could it be that if the lab had placed the concrete very slowly, taking 9 hr to build the pile, it would have resulted in the gentler slope of Figure 5? See Figure B2 for comparison.
- A3. No, slow placement in the laboratory test would have resulted in even steeper slopes, not gentler slopes. It takes tremendous energy to make concrete move after it has been in position for even 30 min. The laboratory sample lacked the necessary flow energy to really duplicate field conditions. Its main value was to show the difference between the several mix designs.
- Q4. I believe that the ability of a chemical admixture to reduce water requirements for equal workability (slump/flow, etc.) is beneficial. As Williams pointed out, the admixture reduces cement content required for given workability at a given water content and, hence, gives the needed strength with less heat. This is, however, water reduction—not retardation. Is it just coincidental that most water reducers are also retarders?
- A4. No, the function of the admixture is not to reduce water requirement. This is just a beneficial side effect. The function in tremie concrete is to retard the set and provide a more cohesive cement paste. This improves the flow of the mass which is the key to better tremie concrete.
- Q5. The function of a chemical admixture to retard, i.e., to delay the rate of stiffening, is important in tremie-placed concrete. It is necessary to keep placing for a long time, provided the intent is, as I believe it should be, to get the first batch placed to emerge as the top layer of the placement. In Figure 5 of Williams' paper is it implied that the 5-9 hr concrete (stippled) is on top of the 0-5 hr concrete? Note the reference in the last sentence before the beginning of the "Conclusion" "...each lift was placed on the previous one...". This implies that the top layer is not the first batch. What really happened—so far as you know?
- A5. The top layer on a tremie pour in the area within several feet around the tremie pipe will likely be from the last batch placed. Ten feet away and 20 feet away, the top layer may be from the third, fourth, or fifth batch placed. Tremie concrete does not move uniformly in all directions. One batch is likely to push in one direction, and the other batch will push in a different direction, wherever there is the least resistance at the time.
- Q6. Gerwick in his American Concrete Institute paper, SP-8, says the tremie principle "is to introduce plastic concrete under the surface of the fresh concrete previously placed. Studies show

that tremie concrete flows outward, pushing the existing surface outward and upward." On page 14 he says: "The use of admixtures permits wider spacing of tremie pipes, because of the greater flowability and flatter slopes." Do you agree?

A6. Ben Gerwick is correct that the concrete is introduced under the surface of previously placed concrete, but its final place of repose can be under the surface, at the surface on the downhill slope, or adjacent to the pipe.

Q7. Do you believe that 9-in.-slump concrete has a greater "flowability" if it has a water reducer? It will have less cement at the same water content but 9-in. slump with admixture is not greater than 9-in. slump without admixture, is it?

A7. Yes, 9-in.-slump concrete with Plastiment and air has better flowability than 9-in.-slump concrete with only air-entraining admixture or plain admixture. This is what the three small laboratory samples in the article show graphically.

Q8. If a water reducer is added to a mixture with a 7-in. slump (without water reducer) and the cement content is not reduced, then with the same water content, a 9-in.-slump concrete will result. This 9-in.-slump concrete will have increased flow, flatter slopes, equal strength, equal heat, and greater cost (since the cost includes the same amount of cement plus the admixture). Do you agree?

A8. Yes, I think an admixture at the same cement content would increase cost, but a 7-in.-slump plain concrete would give very marginal results for tremie work. I am told, but do not have details at hand, that a tremie job was poured in Hawaii at 6-in. slump at the insistence of the engineer. Flow was poor to the edges and much laitance resulted. Lifting and resealing the pipe time and again produced numerous gravel pockets. The job was a disaster.

Q9. Do the slopes get "flatter" at the same slump and same time-temperature history? I think not.

A9. Slopes are flatter at the same slump when Plastiment is used in the mix.

Q10. In the Corps of Engineers' Guide Specifications (CE-1401.01), paragraph 12.10, regarding concrete deposited underwater, it says "...the maximum horizontal flow will be limited to 15 ft for nonretarded concrete and 20 ft for concrete containing a retarding admixture" (ASTM C 494 Type B = CRD-C 87), i.e., initial setting time is at least one hour later. Elsewhere it is indicated that the slump of tremie concrete will be constant within small limits. Do you agree?

A10. I disagree with this spec.

Q11. I have assumed that the only reason tremies can be put farther apart when using concrete with a retarder is that more volume of concrete can be pumped down one pipe if the concrete takes longer to stiffen. In other words, the property of the retarded concrete that is relevant to the allowance of wider tremie spacing is the delayed time of stiffening and setting. Do you agree?

A11. No, the reason for putting tremie pipes farther apart is the improved flow characteristics and the more cohesive nature of the cement paste, in addition to the retardation.

Q12. The more retardation, the fewer tremies needed?

A12. Yes, the more retardation the farther the tremie pipes can be spaced.

Q13. Let us assume an extreme case to make the point. In this case it is economical to retard, and it takes 10 days to reach initial set. The batch, mix, and discharge of 1,000-cu-yd process can be carried out in a 24-hr day. It would then follow that a 10,000-cu-yd caisson or bridge pier could be placed with a single tremie pipe. In this instance, it would not matter whether the 10,000 cu yd was in a structure 2 sq yd in cross section, 5,000 yd high (in water 4,999 yd deep); or a structure 5,000 sq yd in cross section, 2 yd high—in completely calm, still water. Do you agree?

A13. You are right, this is extreme, and unless the entire area were under continuous vibration from an earthquake, I doubt that flow would occur as you suggest.

Q14. It is unlikely that a contractor would take 10 days to place concrete if he could produce the needed volume quicker and get it placed in five days using two tremies; but if the limiting factor was batching and mixing then it follows that the example would be valid. Correct?

A14. The quicker the volume of tremie can be placed, the better the flow, and the more uniform the final result.

2. Based on the question and answer interchange between the author and Williams, some additional discussion arose:

Q15. If concrete were a true fluid of density, say twice that of water, and of a viscosity, say twice that of water, and was not miscible with water, and could be introduced into the water-filled volume from the open bottom end of the tremie pipe at any desired rate and could apply, by a pump or otherwise, any desired head, and could avoid turbulence, and the viscosity did not change over time—then any desired volume could be pumped into any desired space of any given depth or width or length from one tremie that always remained about 25 mm off the bottom. Do you agree?

A15. If concrete were a true fluid, everything you assume is certainly correct.

Q16. The factors that interfere with an ideal situation as described above are many and vary in degree of influence under different circumstances. For example, if the ability to flow by adding water is increased the tendency for miscibility with the superjacent water is increased and a consequent layer of dilute crud develops. Correct?

A16. One of the factors that interferes is the fact that concrete is more like a pile of coarse and fine aggregate lubricated with cement paste. The longer the pile stays in position, the less lubrication there is from the paste.

Q17. If, however, the ability to flow is increased by use of a water reducer, but there is no increase in unit water content, this miscibility problem should not arise. Hence, all other things being equal, use of a water reducer should permit increased tremie spacings, shouldn't it?

A17. Yes, the theory of increased spacings is correct when all other factors are constant.

Q18. If the tendency to stiffen is retarded for 24 hr, it should be possible to pump the mixture through the same pipe at the same location for the 24-hr period. This would result in the placement of more concrete per position. Correct?

A18. Retardation makes it possible to bring a mix back into a fluid condition if there is enough mechanical force from flow action or from vibration. Otherwise the retarded mix comes to a state of repose in approximately an hour.

Q19. By increasing the hydraulic pressure some of the factors that reduce flow should be overcome. Oil well cementing companies pump concrete down a pipe 5 miles long by use of high pump pressures. The end of this pipe always remains at the bottom and the concrete that is pumped down first also surfaces first (10 miles later vertically and 6 in. away horizontally). This operation should still be considered a tremie job, even though the space was initially filled with mud rather than water. Do you agree?

A19. Yes, high pressure could force the concrete to move farther and faster. However, it has always been surprising to me how a tremie pipe that has not been used for about 90 min develops tremendous frictional resistance at its tip. This is where the pipe is sometimes lifted too high by the contractor, breaking the seal and providing a pocket of sand and gravel. However, this pocket is hidden and only becomes apparent by coring or by the fact that there is less volume of concrete in the pour than the computed volume indicates.

In accordance with ER 70-2-3, paragraph 6c(1)(b),  
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Tynes, William O

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Engineer Waterways Experiment Station, 1976.

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